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RECENT PROGRESS
IN
DYNAMO-ELECTRIC
MACHINES,

82601

BEING A SUPPLEMENT TO

"DYNAMO-ELECTRIC MACHINERY."

BY

hillips
PROF. SYLVANUS P. THOMPSON,
B.A., D.Sc., M.S.T.E.

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PREFACE.

No preliminary explanation of the object of these lectures can be considered necessary. The title is so explicit, the subject so important, and the author so well known, that explanations are rendered superfluous.

By reprinting from the Magazine, where the lectures appeared as a valuable part of current scientific literature, the publisher has put the lectures in more convenient form for ready use by practical workers.

EDITOR OF VAN NOSTRAND'S MAGAZINE.

RECENT PROGRESS IN DYNAMO-ELECTRIC MACHINES.

FIFTEEN months ago, I had the honor of delivering in this place a course of three Cantor Lectures on "Dynamo-electric Machinery." In the first of those lectures, the endeavor was made to trace out a physical theory of the action of dynamos, and to follow the theory into its bearings upon the construction of such machines. In the second lecture, a large number of actual machines were considered and compared with one another and with the theory; and in the third lecture, the dynamo was considered in its functions as a mechanical motor.

As the present paper may be considered supplementary to the Cantor Lectures, it will be convenient to treat of the features of progress which come to-night under review in a similar order of topics. I, therefore, take up first the theory of the dynamo.

There are, in fact, three distinct theories of the dynamo: (1) a physical theory, dealing with the lines of magnetic force and lines of current in which these quantities are made, without further inquiry into their why or how, the basis of the arguments; (2) an algebraical theory, founded upon the mathematical laws of electric induction and of theoretical mechanics; and (3) a graphical theory, based upon the possibility of representing the action of a dynamo by a so-called "characteristic" curve, in the manner originally devised by Dr. Hopkinson, and subsequently developed by Frölich, Deprez, and others. The last of these three methods, though it has not received any great or striking development during the past year, has proved itself to be the most invaluable aid in the practical construction of dynamo-machines. One has only to refer to the use made of characteristics by Mr. Kapp in his articles on the winding of "compound" dynamos, and, still more recently, by Dr. Hopkinson, in solving certain problems in the electric transmission of energy, to see how invaluable the method is.

In the algebraic theory much progress has been made during the past year; and there certainly was room for it. Monsieur Joubert has published, in the *Journal de Physique* for July, 1883, a long mathematical article, the object of which is to deduce the equations of the dynamo, taking into account not only the action of self-induction in the circuit, but also some of the terms of the second order usually neglected in first approximations. It is a question whether he has not still omitted some terms of quite as great an importance as those retained in the complicated formula deduced by him. But the matter can hardly be discussed in the present paper. Still more recently, Professor Clausius has published in Wiedemann's *Annalen*, for November last, a paper expounding a mathematical theory of dynamo-electric machines far more comprehensive, and, I venture to say, far more true, than any other yet put forward. Without shirking any of the mathematical difficulties presented by the complications of mutual induction between, and self-induction in, the various organs of the machine, and by the admitted incompleteness of all our formula for correcting the magnetism of an electro-magnet with the strength of its exciting current, Prof. Clausius has succeeded in putting the equations into a shape, not only far more satisfactory from the point of view of completeness, but in framing those equations in a manner that must commend itself to every engineer. The relative simplicity attained by Clausius is, in fact, due to his lavish introduction of a set of arbitrary constants, each one of which having values that must be determined by experiment, for each machine or type of machines. The number of new symbols thus introduced is considerable; and it would be very desirable to find names for the separate constants to be determined. An excellent translation has appeared in the *Philosophical Magazine* of this year, and another is in process of publication in *The Electrician*, in which journal the series of articles on the theory of dynamo-electric machines from the pen of Professor O. J. Lodge is still continued. It cannot be said even yet that the mathematical theory of the dynamo is near completion. A further paper by Professor Clausius is promised; and it remains to be seen whether this article will deal with some of those points in which the graphic method has been so useful in practice, for example, in determining the proper quantities of wire for the coils in "self-regulating" or "compound" machines, and in finding the best shape to give to magnets and pole-pieces.

Turning to the physical theory of the dynamo, there is much to record. Our knowledge of the inductive actions which go on between the field magnets and armatures of dynamos has received considerable additions during the past year from the researches of Isenbeck, Cunynghame, Pfaundler and others. There is a good deal to be said on this head, and I have several new results to announce as the result of my own observations. Let me state as my starting point a matter mentioned in my Cantor Lectures, namely, the distribution of potential round the collector or commutator of a dynamo. Mr. W. M. Mordey, who first drew my attention to the fact that this distribution was irregular in badly-designed machines, had devised the following method of observing it. One terminal of a voltmeter was connected to one of the brushes of the dynamo, and the other terminal was joined by a wire to a small metallic brush or spring, which could be pressed against the rotating collector at any desired part of its circumference. I then made the suggestion that these indications might with advantage be plotted out round a circle corresponding to the circumference of the collector. Figs. 1 and 2, which are reproduced from my Cantor Lectures, serve to show how the potential in a good Gramme machine rises gradually from its lowest to its highest value. The same values as are plotted round the circle in Fig. 1 are plotted out as vertical ordinates upon the level line in Fig. 2. I made the remark at the time that if the magnetic field in which the armature rotated were uniform, this curve would be a true "sinusoid," or curve of sines; and that the steepness of the slope of the curve at different points would enable us to judge of the relative idleness or activity of coils in different parts of the field. About the same time, I developed this method of observation a little further, and used two small metal brushes, at a distance apart equal to the width between the middle of two consecutive bars of the collector of my little Siemens dynamo, for the same purpose.* As the collector rotated, these two little brushes (see Fig. 3) gave on the voltmeter an indication which meas-

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* Dr. Isenbeck has also independently used a similar arrangement to investigate the induction going on in a Gramme dynamo.

Fig. 1

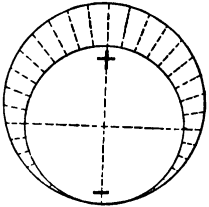
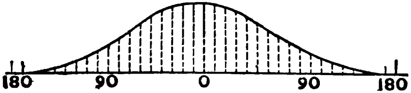


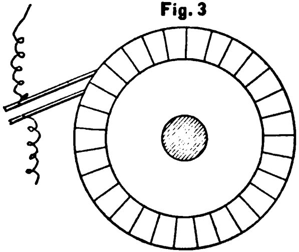
Diagram of Potential round the Collector of Gramme Dynamo.

Fig. 2



Horizontal Diagram of Potentials at Collector of Gramme Dynamo.

Fig. 3



Method of Experimenting at Collector of Dynamo.

ured exactly the activity of the induction, in that section of the armature which was passing through the particular position in the field corresponding to the position of the contacts. I found, in the case of my Siemens dynamo, that the result was fairly satisfactory, for the difference of potential indicated was almost *nil* at the sections close to the proper brushes of the machine, and was a maximum about halfway between. In fact, the difference of potentials was rising most markedly at 90° from the usual brushes, or precisely in the region where (as seen in Fig. 2) the slope of the curve of total potential was greatest. One immediate result of Mr. Mordey's observations on the distribution of potential, and of my method of mapping it, may be recorded. I pointed out to Mr. Mordey that in a dynamo where the distribution was faulty, and where the curves of total potential showed irregularities, the fault was due to irregularities in the induction at different parts of the field; and that the remedy must be sought in changing the distribution of the lines of force in the field by altering the shape of the pole-pieces. I am able now, after the lapse of fifteen months, to congratulate Mr. Mordey on the entire and complete success with which he has followed out these suggestions. He has entirely cured the Schuckert machine of its vice of sparkling. The typical bad diagram given in my Cantor Lectures was taken from a Schuckert machine before it received from his hands the modifications which are so signally successful to-day.

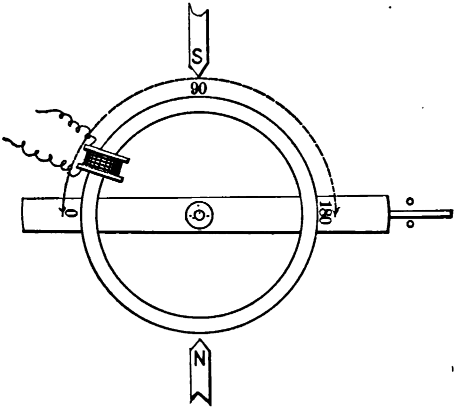
Since the experiments above detailed, I have experimented on my Siemens dynamo in another way. The machine was dismounted, and its field magnets separately excited. Two consecutive bars of the collector were then connected with a reflecting galvanometer having a moderately heavy and slow moving needle. A small lever clamped to the collector allowed the armature to be rotated by hand, through successive angles equal to 10°, there being thirty-six bars to the collector. The deflections obtained of course meas ured the intensity of the inductive effect at each position. The result confirmed those obtained by the method of the two wire brushes.

I mention these methods, which have been used in my laboratory at Bristol, and have not been published before, because they relate strictly to the physical theory of the dynamo as developed in my Cantor Lectures, and also because of their practical application to all dynamos in which any such defect appears. They are also very closely related to the researches of Dr. Isenbeck, which next claim attention.

Dr. Isenbeck described, in the *Electrotechnische Zeitschrist* for last August, a beautiful little apparatus for investigating the induction in the coils of a Gramme ring, and for investigating the influence exerted by pole-pieces of different form upon these actions.

Isenbeck's apparatus (Fig. 4) consists of a circular frame of wood placed between the poles of two small bar-magnets of steel, each 25 centimeters long, lying

Fig. 4



Isenbeck's Apparatus.

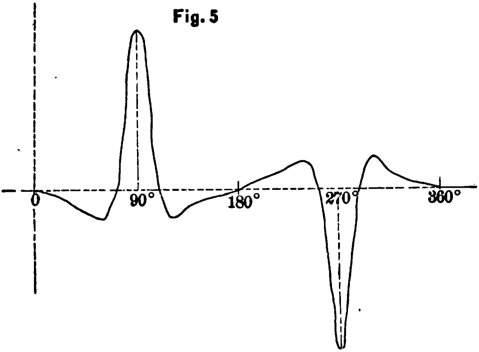
25 centimeters apart. On the frame, which is pivoted at the center, is carried a ring of wood or iron, upon which is placed at one point a small coil of fine wire. This corresponds to a single section of the coils of a Pacinotti or of a Gramme ring, of which the ring of wood or iron constitutes the core. The coil can be adjusted to any desired position

on the ring, and the ends communicate with a galvanometer. On vibrating it isochronously with the swing of the needle of the galvanometer, the latter is set in motion by the induced currents, and the deflection which results shows the relative amount of induction going on in the particular part of the field where the coil is situated The vibrations of the frame are limited by stocks to an angle of 7° 5′. Pole-pieces of soft iron, bent into arcs of about 160° so as to embrace the ring on both sides, but not quite meeting, were constructed to fit upon the poles of the magnets. In some of the experiments a disc of iron was placed internally within the ring; and in some other experiments a magnet was placed inside the ring, with its poles set, so as either to reinforce, or to oppose, the action of the two external poles. In Dr. Isenbeck's hands this apparatus yielded some remarkable results. Using a wooden ring, and poles destitute of polar expansions, he observed a very remarkable inversion in the inductive action to take place at about 25° from the position nearest the poles.

Fig. 4 is a sketch of the main parts of Isenbeck's instrument, and shows the small coil mounted on the wooden ring, and capable of being vibrated to and fro between stops. When vibrated at 0°, or in a position on the diametral line at right angles to the polar diameter, there is no induction in the coil; but as the coil is moved into successive positions round the ring towards the poles, and vibrated there, the induction is observed first to increase, then die away, then begin again in a very powerful way, as it nears the pole, where the rate of cutting the lines of force is a maximum. This powerful induction near the poles is, however, confined to the narrow region within about 12° on each side of the pole. It is beyond these points that the false inductions occur, giving rise in the coil, as it passes through the regions beyond the 12°, to electromotive forces opposing those which are generated in the regions which are close to the poles.

These inverse inductions were found by Isenbeck to be even worse when an iron disc or an internal opposing magnet was placed within the ring; but a reinforcing magnet slightly improved matters. Of course such an action in a Gramme armature going on in all the coils, except in those within 12° of the central line of the poles, would be most disastrous to the working of the machine; and the rise of potential around the collector would be anything but regular. In Fig. 5 I have copied out Isenbeck's curve of induction for the con-

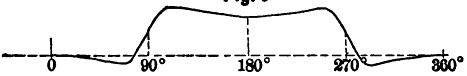
Fig. 5



secutive four quadrants. From 0° to 90° the exploring coil is supposed to be vibrated in successive positions from the place where, in the actual dynamo, the negative brush would be, around to a point opposite the S pole of the pointed field magnet. From 90° to 180° it is passing around to the positive brush; from 180° to 270° it passes to a point opposite the N pole; and from 270° to 360° returns to the negative brush. Now, since the height of this curve, at any point, measures the induction going on in a typical section as it moves through the corresponding region of the field, and since in the actual Pacinotti or Gramme ring the sections are connected all the way around the ring, it follows that the actual potential at any point in the series of sections will be got by adding up the total induced electromotive force up to that point. In other words, we must integrate the curve to obtain the corresponding curve of potential corresponding with the actual state of things around the collector of the machine. Fig.

6 gives the curve as integrated expressly for me from Fig. 5 by the aid of the very ingenious curve integrator of Mr. C. Vernon Boys. The height of the ordinate of this second curve at any point is proportional to the area enclosed under the first curve up to the corresponding point. Thus the height at 90° in the second curve is proportional to the total area up to 90° below the first curve. And it will be noticed that though the induction (first curve, Fig. 5) decreases after 90°, and falls to zero at about 102°, the sum of the potentials (second curve, Fig. 6) goes on increasing up to 102°, where it is a maximum, and after that falls off, because, as the first curve shows, there is from that point onwards till 180° an opposing false induction. If this potential curve were actually observed on any dynamo, we might be sure

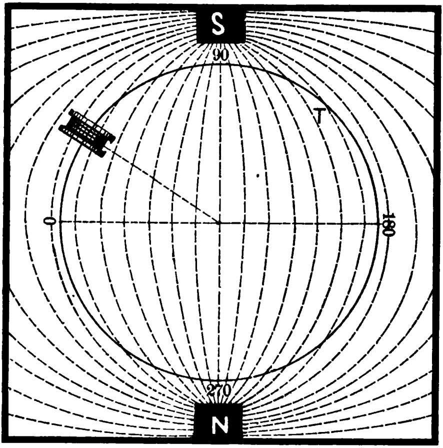
Fig. 6



that we could get a higher electromotive force by moving the brush from 108° to 102°, or to 258°, where the potential is higher. Any dynamo in which the curve of potentials at the commutator presented such irregularities as Fig. 6, would be a very inefficient machine, and would probably spark terribly at the collector. It is evident that the induction in some of the coils is opposing that in some of the adjacent coils.

Two questions naturally arise: Why should such detrimental inductions arise in the ring? and how can they be obviated? The researches of Dr. Isenbeck supply the answer to both points. Dr. Isenbeck has calculated from the laws of magnetic potential the number of lines of force that will be cut at the various points of the path of the ring. He finds that the complicated mathematical expression for this case, when examined, shows negative values for angles between 12° and 90°. The curves of values that satisfy his equations have minima exactly in those regions where his experiments revealed them. This is very satisfactory as far as it goes. But we may deduce a precisely similar conclusion in a much simpler manner, from considering the form and distribution of the lines of magnetic force in the field. These are shown in Fig. 7, together with the exploring coil situated as in Fig. 4. A simple inspection of the figure will show that at 0° a certain number of lines of

Fig. 7



force would thread themselves through the exploring coil. As the coil moved around toward the S pole, the number would increase at first, then become for an instant stationary, with neither increase nor decrease; after that a very rapid decrease would set in, which, as the coil passed the 90° point, would result in there being no lines of force through the coil. But at the very same instant the lines of force would begin to crowd in on the other side of the coil, and the number so threaded through negatively would increase until the coil turned around to about the position marked T, where the lines of force are nearly tangential to its path, and here the inversion would occur, because, from that point onwards to 180°, the number of lines of force threaded through the coil would decrease. We see, then, that such inversions in the induction must occur of necessity to a small coil rotating in a magnetic field in which the lines of force are distributed in the curved directions, and with the unequal density which this disposition of the field magnets presents. The remedy is obvious: arrange a more uniform field in which the lines of force are more equally distributed, and are straighter.

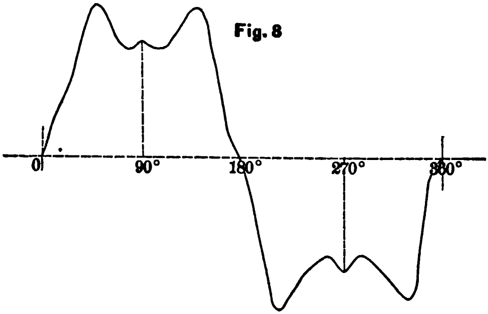
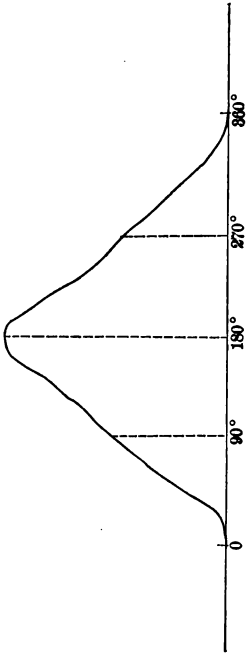


Fig. 8

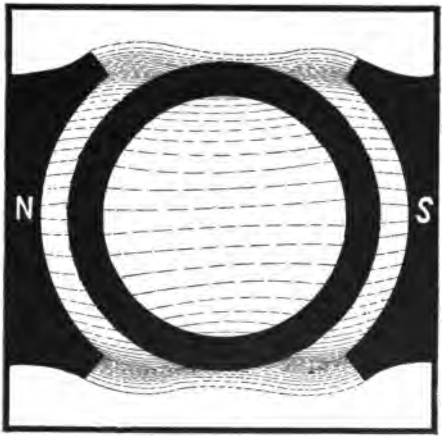
If an iron core be substituted for the wooden core the useful induction is greater and the false induction less; there is still an inversion, but it takes place at about 25° from the pole, and is quite trifling in amount. The introduction of iron pole-pieces extending in two nearly semi-circular arcs from the magnets on either side has, if the wooden ring be still kept as a core, the effect of completely changing the induction, so that the curve, instead of showing a maximum at 90° from starting, shows one at about 10°, and another at 170°. If, however, we make the double improvement of using the iron pole-pieces and the iron core at the same time, the effect is at once changed. There are no longer any inversions, though the induction shows some peculiarity still. Fig. 8 shows the curve of induction adapted from Dr. Isenbeck's paper, and Fig. 9 the curve of potential, which I have had integrated from it. Looking at Fig. 8 we see that on starting from 0° induction soon mounts up, and becomes a maximum at about 20°, where the coil is getting well opposite the end of the encircling pole-piece. From this point on, though the induction is somewhat less, it still has a high value, showing a slight momentary increase as the coil passes the pole at 90°, and there is another maximum at about 160°, as the coil passes the other end of the pole piece. My integrated curve (Fig. 9) tells

Fig. 9



us what would go on at the collector if this were the action in the connected set of coils of a Pacinotti or Gramme ring. The potential rises from 0° all the way to close upon 180°. Still this is not perfect. In the perfect case the potential curve would rise in a perfect harmonic wave form, like that shown in Fig. 2. Fig. 9 departs widely from this, for it is convex from 0° to 90°, and concave between 90° to 180°. But there are no inversions. The cause of the improvement is easily told: The field—such as there is between the pole-piece and the core—is "straighter," and the density of the lines of force in it more uniform. I proved this experimentally in 1878, by the simple process of examining the lines of force in such a field by means of iron filings; the actual filings, secured in their places upon a sheet of gummed glass, were sent to the late Mons. Alfred Niaudet, who had requested me to examine the matter for him. Fig. 10 shows the actual field between the encircling pole-pieces and the iron ring. It will be seen that, though nearly straight in the narrow intervening region, they are not equally distributed, being slightly denser opposite the ends of the pole-pieces. One other case examined by Dr. Isenbeck, we

Fig. 10



will glance at. The effect of introducing within the ring an interior magnet, having its S pole opposite the external S pole, and its N pole opposite the external N pole, was found to assist the action. The induction curve is represented in Fig. 11. As will be seen, there are two maxima at points a little beyond the ends of the pole-pieces, as before; but in between them there is still a higher maxi-

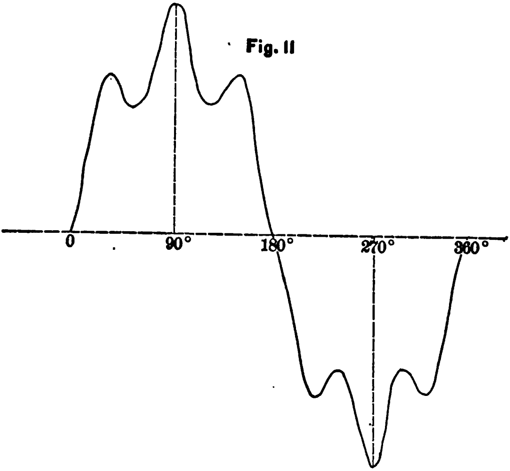


Fig. 11

mum, right between the poles. This case also has been integrated on Mr. Boys' machine, and shows the potential curve of Fig. 12. This curve is a still nearer approach to the harmonic wave form, being concave from 0° to 90°, and convex from 90° to 180°.

I pass from Dr. Isenbeck's researches, and the integrated curves of potential which I have deduced from them, to

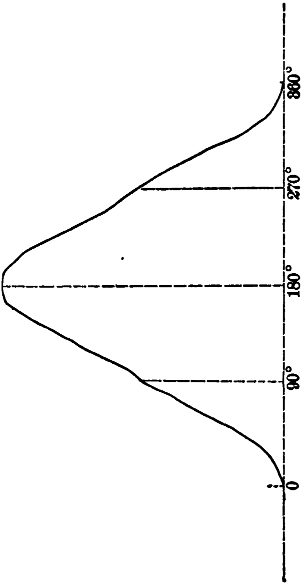
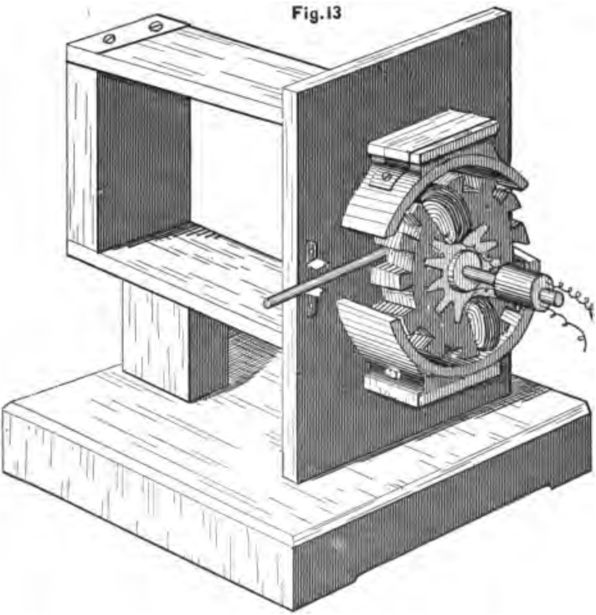


Fig. 12

some further researches of my own, which were undertaken with the view of throwing some light on the question whether the Pacinotti form of armature, with protruding iron teeth, or the Gramme form, in which the iron core is entirely overwound with wire, is the better. It has been assumed without, so far as I am aware, any reason assigned, that the Gramme ring was an improvement on that of Pacinotti. Pacinotti's was of solid iron, with teeth which projected both outwards and inwards, having the coils wound between. Gramme's was made "either out of one piece of iron, or of a bundle of iron wires," and had the coils wound "around the entire surface." Now the question whether the Gramme construction is better than the Pacinotti or not, can readily be tested by experiment. And experiment alone can determine whether it is better to keep a thickness of wire always between pole-pieces and the core, or to intensify the field by giving to the lines of force the powerful reinforcement of protruding teeth of iron. The apparatus I have constructed for determining this point is now before you. It is sketched in Fig. 13.

First there are a couple of magnets set in a frame so as to give us a magnetic field, and there are pole-pieces that can

Fig. 13



be removed at will; in fact, there are three sets of pole-pieces for experimenting with different forms. Between the poles is set an axis of brass, upon which the armatures can be slid. These armatures are three in number. One is shown in Figs. 14 and 15, and consists of two coils of fine wire wound upon a wooden ring; another armature is exactly like

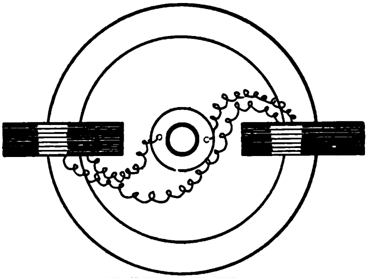


Fig. 15

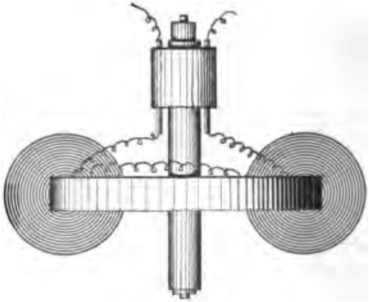


Fig. 14

this, but is built up on a ring of iron wire; a third (shown in its place in Fig. 13) is constructed upon a toothed ring made up of a number of plates of ferrotype iron, cut out and placed flat upon one another. On each of the armatures are wound two coils at opposite ends of a diameter. The coils contain precisely equal lengths of silk-covered copper wire, cut from one piece. The cross section of the core within each of these coils is in each case a square, of one centimeter in the side, so that the number of turns in each coil is as nearly equal as possible. I can slip any one of these armatures into the field, and connect it with a galvanometer. There is a lever handle screwed to the armature, by means of which it can be moved. I have used two methods of proceeding in order to compare the coils. One of these methods is to turn the armature suddenly through a quarter of a revolution, so that the coils advance from 0° to 90°, when the " throw " of the needle of the galvanometer—which is a slow beat one—gives me a measure of the total amount of induction in the armature. The results are as follows:

GRAMME. Wooden Ring.	GRAMME. Iron Ring.	PACINOTTI. Iron Toothed Ring.
5	24	50

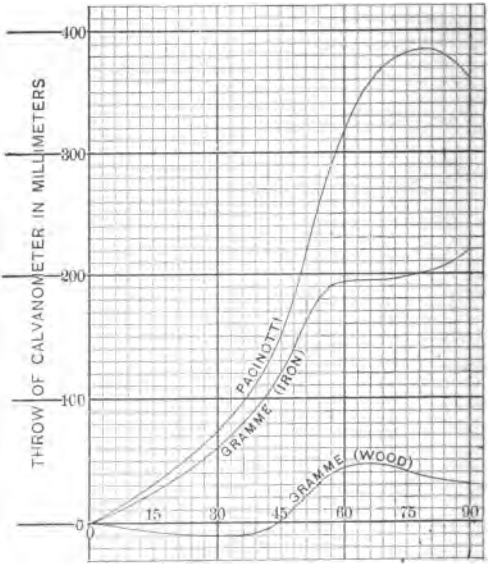
My second method of using these armatures consists in jerking the coils through a distance equal to their own thickness, the coils being successively placed at different positions in the field, the throw of the galvanometer being observed as before. Each of the coils occupies as nearly as possible 15° of angular breadth. Accordingly I have two stops set, limiting the motion of the handle to that amount, and at the back there is a graduated circle enabling me to set the armature with the coils in any desired position. If we move the coils by six such jerks, through their own angular breadth each time, then starting at 0°, the sixth jerk will bring us to 90°. I have plotted out in Fig. 16 the three curves thus obtained, and the corresponding numbers are given in the following table:

	GRAMME.	GRAMME.	PACINOTTI.
	Wooden Ring.	Iron Ring.	Iron Tooth'd Ring.
0°–15°	5	25	30
15°–30°	10	60	70
30°–45°	0	120	140
45°–60°	45	195	320
60°–75°	40	200	380
75°–90°	30	220	360

These figures leave no doubt as to the question at issue. The Gramme pattern of ring armature, so far from being an improvement on the Pacinotti, is distinctly a retrograde step; always supposing that the cost of construction, liability to heating, and other kindred matters be equal for the two. The significance of this point will be resumed at a later period in this paper.

Before leaving the theory of armatures to pass to that of field magnets, I should wish to say that the experiments which I have made, and also those of Dr. Isenbeck, have been so instructive to myself that I have already begun a similar series

Fig. 16



of observations on other forms of armature. I hope in due time to make known the results of my investigations.

But little advance has been made in theory so far as relates to field magnets. The law of saturation of an electro-magnet remains still an empirical law. It is satisfactory, however, that such widely differing authorities as Prof. Clausius, M. Marcel Deprez, and Professors Ayrton and Perry, agree in accepting the empirical formula of Frölich as a sufficiently accurate expression for the law of saturation.

Some progress has been made in the theory of the lead that must be given to the brushes of the dynamo. Formerly this was ascribed to a sluggishness in the demagnetization of the iron of the armature; but in 1878 the late M. Antoine Breguet suggested as a reason the influence of the actual current circulating around the armature coils, which would tend to produce in the iron of the armature a magnetization at right angles to that due to the field magnets.

Breguet showed that there would be a resultant oblique direction of the lines of magnetization in the field, and therefore, since the " diameter of commutation" is at right angles to this direction, the brushes also must be displaced through an equal angle. Clausius accepts this view in his recent theory, and adopts for the angle of the resultant field that whose tangent is the ratio of the two magnetizing forces due to the field magnets and the current in the armature respectively. Professors Ayrton and Perry have also pointed out that there will be an additional displacement of the resultant poles of the armature, consequent upon the self-induction going on in the armature coil between its different sections. In their paper on the government of motors, in which they have brought out this point, they, however, take the view that part of the displacement of the pole is due to the sluggishness of demagnetization of the iron. I do not think, however, that this can be maintained. No experimental proof has ever been given that there is any such thing as a true magnetic lag; the apparent magnetic sluggishness of thick masses of iron is demonstrably due to internal induced currents; and no one uses solid iron in armature cores for this very reason. Neither has it been shown that thin iron plates or wires, such as are used in armature cores, are slower in demagnetizing than magnetizing. Indeed, the reverse is probably true; and, until further experimental evidence is forthcoming, I shall assume that there is no magnetic lag in properly laminated iron cores.

It may here be pointed out that, assuming as a first approximation that the rule that the tangent of the angle of lead represents the ratio between the magnetizing power of the field magnets and of the armature coils, the lead may be diminished to a very small quantity, by increasing the relative power of the field magnets, a course which is for many other reasons advisable. All practice confirms the rule that the magnetic moment of the field magnets ought to be very great as compared with that of the armature. Further than this there ought to be so much iron in the armature as to be just saturated when the dynamo is working at its greatest activity. If there is less than this it will become saturated at a certain point, and when any currents greater than this are employed, the lead will alter, for then the magnetic effect due to the current in the armature will be of greater importance relatively to that due to the field magnets. For the same reason the lead will be more constant when the field magnets are under their saturation point than when quite saturated. In short, every cause that tends to reduce the lead makes the lead more constant, and therefore tends to reduce sparking at the brushes. And the best means to secure this is obviously to use an unstinted quantity of iron—and that of the softest kind—both in the field magnets and in the armature, for then the currents circulating in the armature will have less chance of perturbing the field.

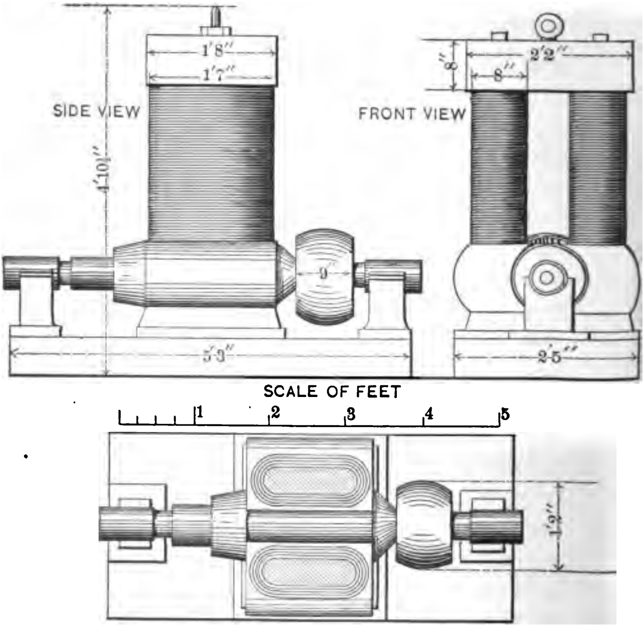
In relation to the magnetism of field magnets, it may be pointed out that the "characteristic" curves now so much used for the study of the action of dynamo machines, which show the rise of the electromotive force of the machine in relation to the corresponding strength of the current, are sometimes assumed, though not quite rightly, to represent the rise of magnetization of the field magnets. Now, though the magnetization of the magnet may attain to practical saturation, it does not, under a still more powerful current, show a magnetization less than saturation. But the characteristics of nearly all series-wound dynamos show—at least for high speeds—a decided tendency to turn down after attaining a maximum; and for some machines, for example, the Brush, this diminution of the electromotive force is very marked. The electromotive force diminishes, but the magnetism of the field magnets does not. An explanation of this dip in the characteristic has lately been put forward by Dr. Hopkinson in his lecture on "Electric Lighting," before the Institution of Civil Engineers, attributing this to the reaction of self-induction and mutual induction between the sections of the armature. No doubt this cause contributes to the effect, as all such reactions diminish the effective electromotive force. I am inclined, however, to think that the greater part of the effect is due to the shifting of the effective line of the field in consequence of the iron of the field magnets becoming saturated before the armature is so. It is at least significant that in the Brush machine, where the reduction of the electromotive force is very great, there is also such a mass of iron in the armature, and so variable a lead at the brushes.

Another point in which theory has for long been ahead of practice, is in the advantage to be gained by working as nearly as possible with closed magnetic circuits; that is to say, with a nearly continuous circuit of iron to conduct the lines of magnetic force round into themselves in closed curves. The enormous importance of this was pointed out so far back as 1878 by Lord Elphinstone and Mr. C. W. Vincent, whose dynamo embodies their idea. Every electrician knows that if a current of electricity has to pass through a circuit, part of which consists of copper, and part of liquids—such as the acid in a battery, or the solution in an electrolytic cell—the resistance of the liquid is, as a rule, much more serious than the resistance of the copper. Even with dilute sulphuric acid the resistance to the flow of the current by a thin stratum is 200,000 times as great as would be offered by an equally thick stratum of copper. And in the analogous case of using a field magnet to magnetize the iron core of an armature, the stratum of air—or, it may be, of copper wire—in between the two pieces of iron, offers what we may term a relatively enormous resistance to the magnetic induction. If we take the magnetic permeability of iron as 1, then the permeability of air is something like $\frac{1}{20000}$, and that of copper is not very different. Or, in other words, a stratum of air or copper offers about 20,000 times as much resistance to the magnetic induction as if the space was filled with soft iron. Obviously, then, it would be a gain to diminish as much as possible the gaps between the portions of iron in the circuit. The values of the magnetic permeability for iron, air, and copper have been known for years, yet this simple deduction from theory has been set at defiance in the vast majority of cases. We have had, a few minutes ago, an experimental proof that the Pacinotti ring, so far from having been "perfected" or "improved" by Gramme, as some very high authorities say, is vastly inferior to it. It will perhaps be intelligible now why Pacinotti's design was essentially right.

I now pass on to the progress recently made in the practical construction of dynamo-electric machines. Thanks to the kindness of several of those by whom this progress has been achieved, I am able to put before you their very latest results.

The Edison dynamo has, during the past eighteen months, received very material improvements at the hands of Dr. Hopkinson, F. R. S. Some of these improvements relate to the field magnet; others to the armature. Dr. Hopkinson has, in the first place, abolished the use of the multiple field magnets, which in the Edison "L," "K," and "E" machines were united to common pole-pieces, and instead of using two, three, or more round pillars of iron, each separately wound, he puts an equal mass of iron into one single solid piece of much greater area of cross-section and somewhat shorter length. One such iron mass, usually oval or oblong cross-section, is attached solidly to each pole-piece, and the two are united at the top by a still heavier yoke of iron. The machines have, consequently, a more squat and compact appearance than before (Fig. 17). It may be remarked, in passing, that the use of multiple pillars of iron used by Edison in the "L," "K," and "E" machines must have been prejudicial, because the currents in those portions of the coils which passed between two adjacent iron pillars must have been opposing each other's magnetizing effect. Dr. Hopkinson has also introduced the improvement of winding the magnets with a copper wire of

Fig. 17



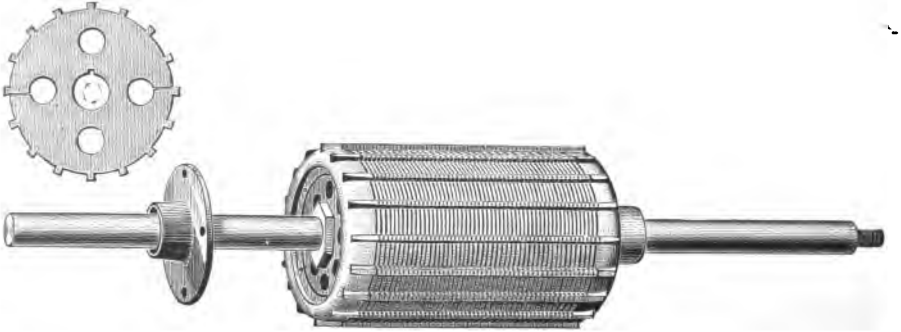
Edison-Hopkinson Dynamo.

square section, wrapped in insulated tape. This wire packs more closely round the iron cores than an ordinary round wire. In the armature the following change has been made. The iron cores in the older Edison machines were made of thin iron discs, separated by paper slipped on over a sleeve of *lignum vitæ,* and held together by six longitudinal bolts passing through holes in the core-plates, and secured by nuts to end-plates. These bolts are now removed, and the plates are held together by great washers, running upon screws cut on the axle of the armature. The size of the central hole in the plates has been diminished, thus getting into the interior more iron, and providing a greater cross-section for the magnetic induction. By these improvements, a machine occupying the same ground space, and of about the same weight as one of the older "L," 150-light machines, is able to supply 250 lights, the efficiency being at the same time improved. In the new 250-light machine, the diameter of the armature is 10 inches; its resistance, cold, is 0.02 ohm; that of the magnet is 17 ohms. The characteristic curve of the machine shows that even when doing full duty, the field magnets are far from being saturated. It will be remarked that, in the older construction, the bolts and their attached end-plates furnish a circuit in which idle currents were constantly running wastefully round, with consequent heating and loss. An Edison 60-light "Z" machine of the older pattern, tested by the committee of the Munich Exhibition, was found to give an efficiency which, if measured by the ratio of external electric work to total electric work, exceeded 87 per cent.; but its commercial efficiency—the ratio of external electric work to the mechanical energy imparted at the belt—was only, at the most, 58.7 per cent. In a recent test made by Mr. Sprague, at Manchester, on an improved dynamo (a 200-light machine), the efficiency of electrical conversion exceeded 94 per cent., and the commercial efficiency 85 per cent.

The Edison Company states that "the weight and cost of the machines per lamp are greatly reduced," but they add a table from which it appears that the old 250-light machine cost £250, while the new 250-light machine costs £265, if made as a fast-speed machine, and £425, if constructed as a slow-speed machine.

The Siemens' machines have not been much altered during the past year; and it is a little difficult to describe the improvements which have been made, as the firm of Siemens Bros. decline, for commercial reasons, to furnish data for publication. Progress has, however, been made by this firm, especially with their compound-wound machines, of which some account has been given by Herr E. Richter, in the *Electrotechnische Zeitschrift.* It appears that three methods of combination have been tried. The shunt and series coils have been wound on different arms of the magnets; they have been wound on separate short frames, and slipped on to the cores side by side, and they have been also wound over one another. In the latest machines the series coils are wound outside the shunt windings. The regulation, judging

Fig. 18.

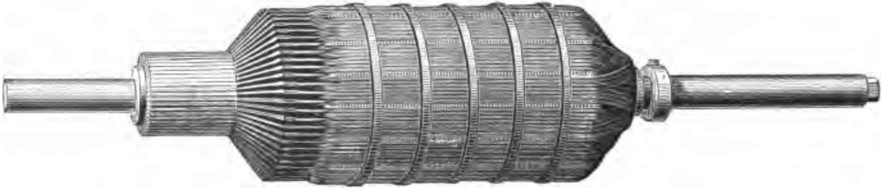


Core of Weston Armature.

by the curves given by Herr Richter, is not perfect. The best regulation was from a "*g*D 17" machine, of which two of the magnet limbs were wound with shunt coils of 29 layers of a 1 millimeter wire, and the other two with two layers of a 3.5 millimeter wire. The potential varied from 64 to 69 volts when the number of lamps was reduced from 20 to 9.

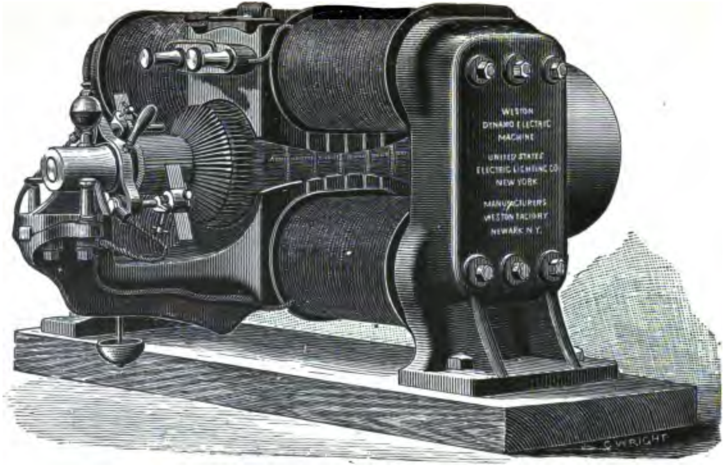
The Weston machine has an armature more or less resembling those of the Siemens' machines. The core is built up of discs of iron of the form shown in Fig. 18, strung together, and presenting projecting teeth all along the surface of the cylinder. Fig. 19 shows the armature when completed. In this machine, as is also evident from Fig. 20, the pole-pieces are laminated to obviate eddy currents and heating. Recently, Mr. Weston has adopted a method of winding the armature with two circuits, so that an accident to one section shall not completely break down the machine. The latest of the Weston machines show

Fig. 19.



Weston Armature.

Fig. 20.



Weston Dynamo.

substantial design, and many improvements in detail upon the older forms.

The machines of the Gramme type next come in for consideration. In those of the actual Gramme pattern I cannot learn that any important improvement has been made in this country; but in the States the Fuller Electrical Company, which holds the Gramme and Wood patents, has brought out several improved forms of machine, in which mechanical engineering skill of a high order is apparent. The field magnets, frames and pole-pieces are very substantial, the ring is better built than the European types, and the collector bars are prevented from flying to pieces by the addition of an insulated ring shrunk on over their ends. In France, too, the machine has received important modifications at the hands of M. Marcel Deprez. M. Deprez's dynamo has two Gramme rings upon one axle, which lies between the poles of two opposing field magnets, each of the two branched, or so-called horse-shoe form. These are laid horizontally, so that the north pole of one is opposite the south pole of the other, and *vice versa*, the poles being provided with curved pole-pieces between which the rings revolve. M. Deprez, who has given much attention to the question how to design a machine which, with the least expenditure of electric energy, gives the greatest actual couple at the axle, is of opinion that the horse-shoe form of electro-magnet is the most advantageous. The iron cores and yokes of the field magnets are very substantial, but the pole-pieces are not very heavy. M. Deprez's machine has a very elaborate system of sectional windings of the field magnets and a switch board, enabling him to couple up the connections in various ways. The circuits of the two rings are quite distinct, and each armature has its own collector and brushes. M. Deprez has also constructed other Gramme machines, with armatures of very fine wire, for his experiments on the electric transmission of power.

Another machine, having as an armature an elongated ring, somewhat like that of the Maxim dynamo, was shown during last autumn at the Fisheries Exhibition, under the name of the Hockhausen dynamo. The field magnets of this machine are very strangely disposed, the ring being placed between two straight electro-magnets placed vertically over one another, the upper magnet being held in its place by curved flanking pieces of iron, which run down the two sides of the machine, and connect the topmost point of the upper magnet with the lowest part of the lower. This arrangement, which strikes the eye as being both mechanically and magnetically bad, is claimed as one of the virtues of the machine, which, in spite of its magnets, appears to be a very good working machine. Its armature is constructed of four separate curved iron frames, upon which the previously wound coils are slipped, and which are then bolted together and secured to strong end plates. I have not seen any report on the efficiency of this machine.

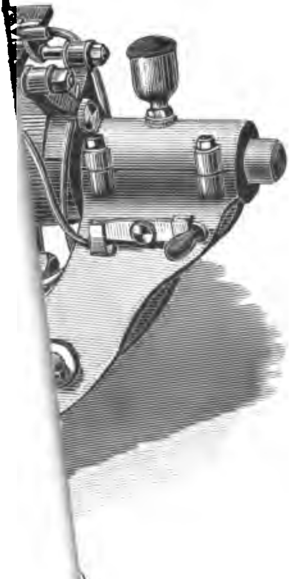
We next come to the class of machines

in which a flattened Gramme ring is used, and of which the machines of Fein, Schuckert and Gülcher are the best known types.

Mr. Gülcher has been steadily at work improving his dynamo in its various mechanical and electrical details. In particular, he has devoted attention to the winding of the field magnets, so as to secure a constant potential at the terminals. After experimenting with various methods of compounding, he finds that the best results are arrived at in the following way: In his four-pole dynamo there are eight cores to be wound. Each of these receives a shunt coil of fine wire, and outside this a main coil of stout wire. The eight fine wire coils are then joined up in series with one another, and connected as a shunt to the terminals; whilst the eight main circuit coils are joined up in parallel. In proof of the degree of accuracy attained by this method Mr. Gülcher has given me many numerical data from actual tests. All of them show a very fair approximation to a constant potential, and an actually-attained constancy for a considerable range. For example, a 4-pole machine, intended to give 65 volts, gave that figure exactly, when the external current varied from 30 to 88 amperes; and gave 64 volts at 63.5 amperes, 63.5 volts at 130 amperes. With one ampere only, the potential was 61.5 volts. Mr. Gülcher adds that, in spite of all possible care in manufacture, very large machines do not give results as satisfactory as those given by machines of somewhat smaller dimensions, though the machines are of identical type, and their parts calculated from the same formulæ. He thinks this to indicate that to obtain the same ratio of out-put and efficiency to weight, there ought to be a corresponding increase made in the electromotive force of the machine. In other words, the means taken in large machines to keep down the electromotive force to equality with that of the smaller machines are detrimental to the action of the machine.

The Anglo-American Electric Light

Corporation has been manufacturing during the past year a dynamo of the flattering type, under the patents of Schuckert and Mordey, to which the not very apt name of the "Victoria" dynamo has been given. By the kindness of Mr. F. Wynne, general manager of the Corporation, and of Mr. Mordey, and Mr. P. Sellon, I have been able to learn a great deal about this machine, and to test personally its capabilities. There are two types of the new Schuckert-Mordey dynamo, one having 4, the other 8 poles arranged round the ring. As mentioned earlier in this paper, Mr. Mordey has given great attention to the form of the pole-pieces. These pole-pieces, in the earlier Schuckert machines, consisted of hollow iron shoes or cases which occupied a large angular breadth along the circumference of the ring. Similar hollow polar extensions are still used in the Gülcher machines (see Fig. 26 of my Cantor Lectures). Mr. Mordey has found my opinion, based upon the diagrams of potential at the collector, to be correct, that these wide-embracing pole-pieces were responsible for false inductions, giving rise to opposing electromotive forces and setting up secondary neutral points at the collectors. He has, therefore, by long extended experiments, arrived at a form of pole-piece which completely obviates these effects. As will be seen from Fig. 21, which represents the 4-pole Victoria dynamo, the pole-pieces, though they embrace the ring through its whole depth from external to internal periphery, are quite narrow, and do not cover more than 30° of angular breadth of the circumference of the armature. They are of cast iron, and are cast upon the cylindrical cores of soft wrought iron which receive the coils. It may be mentioned that, in the 4-pole Gülcher machines, the wide box-like pole pieces are also cast on wrought iron cores. The armature of the Victoria dynamo resembles in its structure the Pacinotti rather than the Gramme type. Its core is built up of rings cut from sheet charcoal iron, and Mr. Mordey has taken



special pains to ensure that there are no electric circuits made in the bolting together of these cores, each plate being both electrically and magnetically insulated from the adjacent plates. Eddy currents in the core are thus almost entirely obviated. This was far from being the case with some of the earlier machines, in which, as in the Edison machine until Dr. Hopkinson improved it, the bolts holding together the cores constituted an available path for wasteful inductions. The core rings of the Victoria dynamo are toothed, as in the Pacinotti ring, and the wires are wound in the intervening gaps. There is, moreover, ample ventilation in this armature, a point not to be overlooked. Formerly, in a four-pole machine, four brushes were necessary—as in the Gülcher dynamo and the four-pole Gramme. Mr. Mordey has reduced the number to two, by the device, firstly, of connecting together those segments of the armature coils which occupy similar positions with respect to the poles; and, secondly, of connecting together, by metallic connections, those bars of the collector which are at the same potential. In the four-pole machine opposite bars are thus connected. Two brushes only are then necessary, and these are 90° apart. Fig. 22 gives the actual diagram of the potentials at the collector. There being 60 sections in the ring, there will be 15 segments of the collector from the negative brush to the positive. The potential rises steadily from the negative brush, and becomes a maximum at the positive brush, at 90°, whence it again diminishes to zero at 180°. The bars of the collector being connected, it will be remembered, to those diametrically opposite to them, it follows that the potential will rise from 180° to 270°, precisely as it rose from 0° to 90°, and will again fall to zero in passing from 270° to 0°. If the curve from 0° to 180° were plotted again horizontally, we should clearly see how nearly regular the rise and fall is. If from this curve we were to construct another one, in which the heights of the ordinates

Fig.22

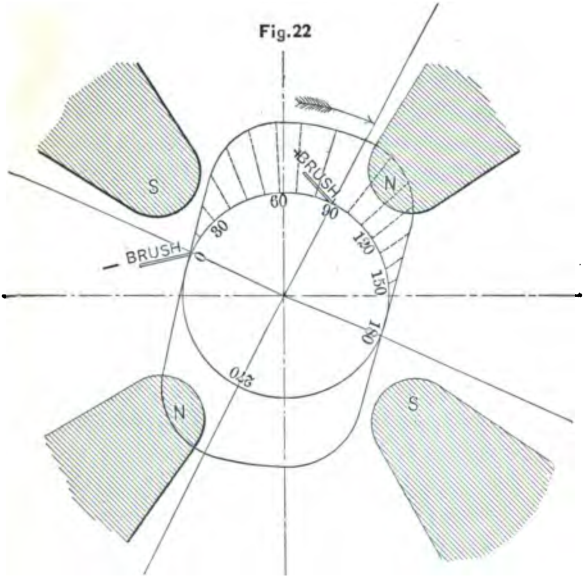
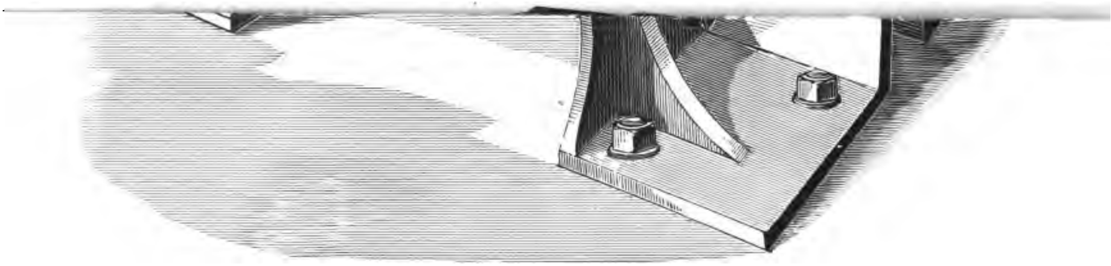


Diagram of Potentials at Collector of 4-Pole Schuckert-Mordey Dynamo.

should correspond to the tangent of the angle of slope of this potential curve—in other words, if we were to differentiate the curve—we should obtain a second curve—the curve of induction. It would show a positive maximum at about 30°, and a negative maximum at about 120°, where the slope up and slope down are steepest in the potential curve. These maxima of induction are situated very nearly opposite the edges of the pole-pieces, on the side toward which the armature is rotating. Apparently the lines of force of the field are the thickest here. In this displacement of the maximum induction we have, I think, the explanation of the inferiority of the earlier machines with broad polar expansions. In those machines the maximum position of induction was displaced to the very edge of the broad pole-piece, and, therefore, the induction was sudden and irregular. It is a singular result that, while in those machines in which the ring armature is extended cylinderwise, there must be wide embracing pole-pieces, in those in which the ring is flattened into a disc shape, the pole-pieces must on no account be wide.

The Victoria dynamo is self-regulating, having all the eight field magnet coils doubly wound, with main circuit coils inside, and shunt coils outside. The characteristic of this machine is wonderfully straight. In a “ D^2 ” machine, wound for a potential of 60 volts, the following values were obtained : Open circuit, 58 volts ; 10 amperes, 58.5 volts; 20 amperes, 59 volts ; 60 amperes, 59.7 volts ; 90 amperes, 59.9 volts ; 120 amperes, 60 volts. It will be seen that for small loads the potential drops a little ; but it is under these circumstances that the engine speed usually rises slightly in practice, so that the constancy of the potential between the mains is somewhat better than the figures would show. In actual practice, the regulation is marvelous. I have myself opened the circuit of a Victoria dynamo which at the time was feeding 101 lamps, 100 being at a distance, 1 lamp attached to the terminals of the machine. On detaching the main wire from the terminal, the 100 lamps were suddenly extinguished. The solitary lamp on the machine did not even wink and there was no flash at the brushes. The sparking was so slight it was impossible to tell whether the machine was an open circuit or whether it was doing full work. The lead was the same under all loads. There are not many dynamos that can show a result of this kind. According to measurements made by the Anglo-American Corporation's electricians, who have published the figures entire, the factor of conversion of this machine is 96.15 per cent., the electrical efficiency 85.68 per cent. These values assume the B. A. unit of resistance as the true ohm, and are, therefore, probably about 1½ per cent. too high. Some of these machines are wound for low speeds for ship lighting. These machines have an electrical activity slightly higher, and an efficiency slightly lower, than the high-speed machines. They also have field magnet cores slightly heavier, requiring, therefore, the expenditure of rather more electrical energy in maintaining the field. These remarks refer, of course, to a comparison between machines wound to light

FIG. 23.



VICTORIA (SCHUCKERT-MORDEY) DYNAMO (8-POLE).

an equal number of lamps, and to work at an equal electromotive force.

A larger type of Victoria machine, having 8 poles, alternately north and south, set around the ring, has also been constructed by the Anglo-American Corporation. This machine (Fig. 23) illuminates 750 incandescent lamps. The ring has 120 sections, there being 15 sections, therefore, between each pole and the adjacent pole of the surrounding set. As each segment of the collector is connected with those situated at 90°, 180°, and 270° distance around the set, only two brushes are required.

A rather singular commentary upon the real superiority of multipolar dynamos having rings of the flattened type over the more compact ring armatures, to which we have been accustomed in the ordinary Gramme machines, is furnished by the announcement within the past month of a new and improved dynamo designed by M. Gramme himself, in which there is a flat-ring armature rotating within a crown of 12 poles. Elaborate illustrations and a detailed description of this latest of dynamos are given in the *Revue Industrielle*, of January 9th, 1884. From this article it appears that in the opinion of M. Gramme the new machine still requires some modifications to make it quite a practical machine. A glance at this drawing is quite sufficient to enable one to hazard a guess at the reasons. The pole-pieces are broad, nearly meeting one another. I should confidently predict from such a design the vice of sparking at the brushes and heating of the collector segments. Moreover, there are no fewer than 24 brushes! Think of the friction of 24 brushes, and the labor of making the complicated holders. It appears that in England we are at least a few steps ahead of France in the matter of designing dynamo machines.

Another 4-pole flat-ring dynamo has been designed by Herr Schuckert, of Nürnberg, and was exhibited at the late Vienna Exhibition. This machine, which had many excellent points in its design, was compound wound, and was calculated to give, at 450 revolutions, a current of 320 amperes at 100 volts.

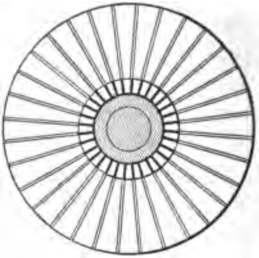
The present drift toward multipolar dynamos of this type is very significant. There is little difference, save in detail, between the 4-pole machines of Gülcher, Schuckert, and the newer "Schuckert-Mordey" dynamo, albeit these differences are not unimportant. But all these constructors agree in adopting the flat ring. The advantage originally claimed for this construction, namely, that it allows less of the total length of wire to remain "idle" on the inner side of the ring, is rather imaginary than real, for the total resistance of the armature is but a small fraction of the whole resistance of the circuit; and it is possible to spread the field so as to make all parts of the wire active without any gain whatever, if by this spreading there is no increase on the whole in the total number of lines of force in the field. The real reasons in favor of multipolar flat-ring armatures appear to be the following: First, their excellent ventilation; second, their freedom from liability to be injured by the flying out of the coils by the tangential inertia (often miscalled centrifugal force) at high speeds; third, their low resistance, due to the fact that the separate sections are cross-connected either at the brushes or in the ring itself in parallel arc. To these may be added, that, with an equal peripheral speed, the armature rotating between four poles undergoes twice as much induction as when rotating between two poles, since it cuts the lines of force twice as many times in the former case as in the latter.

I pass on to the improvements made in the dynamo by Messrs. R. E. Crompton and Co. To describe the course of development which the Bürgin dynamo has undergone in Mr. Crompton's hands would alone occupy a whole evening. The armature of the original machine, as it came from Switzerland, consisted of several rings set side by side on one spindle, these rings being made of iron wire wound upon a square frame, and carrying each four coils. In this form it is described in Professor Adams' Cantor Lectures on "Electric Lighting," in 1881. Mr. Crompton changed the square form to a hexagon having six coils upon it, and increased the number of rings to ten, so that the armature consisted of sixty segments. He then found it advisable to alternate the positions of these instead of placing them in a regular screw order on the spindle, as shown in most of the public drawings of this well-known machine. The next step was to increase the quantity of iron in the hexagonal cores, and to ascertain by experiment what was the best relative proportion of iron and copper to employ. At the same time Mr. Crompton and Mr. Kapp introduced their system of "compounding" the windings of the field magnets. Another change in the armature followed, the rings being made much broader and fewer in number, four massive hexagonal rings, united to a 24-part collector, replacing the ten slighter rings and their 60-part collector. Quite recently Mr. Crompton and Mr. Kapp have again remodeled the style of armature and have produced a machine which, though it is not yet quite completed, shows what may be done in the way of improvement by careful attention to the best proportions of parts and quality of material. The new dynamo weighs 22 cwts. Its field magnets are of the very softest Swedish wrought iron, compound wound. The armature is a single ring of the elongated or cylindrical pattern, and its coils are wound upon an iron core made up of toothed discs of very thin soft iron fixed upon a central spindle, the coil being wound between the teeth as in a Pacinotti ring. In fact, the armature may be described as a kind of cross between those of Weston and Pacinotti, having also something in common in the Bergin armature, at least so I understand, for though I have, by the kindness of Mr. Crompton, been allowed to see the machine, I have had no opportunity as yet of examining the armature. Mr. Crompton's great aim has been to have as complete a magnetic circuit as possible, and that of the best quality. He has sought to increase the intensity of the field by having plenty of iron in the armature, and bringing that iron as close as possible into proximity with the pole-pieces by means of the projecting teeth. The result is an extraordinary increase in the "output," or, as Sir William Thomson puts it, "activity" (*i. e.*, amount of work done per second) of the machine. The machine is only 3 ft. 4 in. long, 12 in. high, and 2 ft. wide. The armature is 17 in. long, and 8 in. diameter. At 1,000 revolutions per minute it gives 110 amperes at 145 volts, or its "activity" is 15,050 watts; but at this speed it heats too much. The power of the field magnets is such that, at all speeds, and under all conditions of the external circuit, the intensity of the field over-masters the magnetizing action of the currents in the armature coils. There is, therefore, hardly any lead at all at the brushes, and what lead there is, is absolutely constant. There is no sparking at the brushes, and it is impossible to tell by looking at the brushes whether the current is off or on. Mr. Crompton is now constructing another machine of the same general design, but larger, to drive 1,000 Swan lamps. This machine, together with its engine, is only about 8 ft. long, 6 ft. high, 2 ft. 4 in. wide, and complete with its bed-plate will weigh only about 8 tons.

It may be mentioned that in Messrs. Crompton's compound dynamos, as also in those of the Anglo-American Corporation, the series coils are wound direct upon the iron cores, and the shunt coils outside them, thus reversing the practice adopted by Messrs. Siemens and by Mr. Gülcher. It might have been expected that theory would have something to say in determining which practice is preferable. If the shunt coils of thin wire are outside, the prime cost for an equal magnetizing effect will probably be greater. If the series coils are outside, the loss by heating in producing an equal magnetic effect will probably be increased. It might have been expected that, as with galvanometer coils, so with the coils of field magnets it would be advantageous to get as many of the turns as close as possible to the core, and, therefore, that the thinner wire should be wound on before the thicker. But, on the other hand, it is advisable to keep down the resistance of the series coils, as they will form part of the main circuit, whilst the additional resistance, necessitated by winding in coils of larger diameter, is not altogether a disadvantage in a shunt coil. If this proves to be the right way of regarding the problem, we shall wind the shunt coils outside those that are in series with the main circuit.

Before leaving the subject of ring armatures I should like to refer to a form recently devised by Signor B. Cabella, which I think might be recommended to amateur constructors of dynamos as being easily made. The Figs. 24 and 25 show its general arrangements. The armature resembles that of the Edison dynamo in being built up of copper

Fig.24

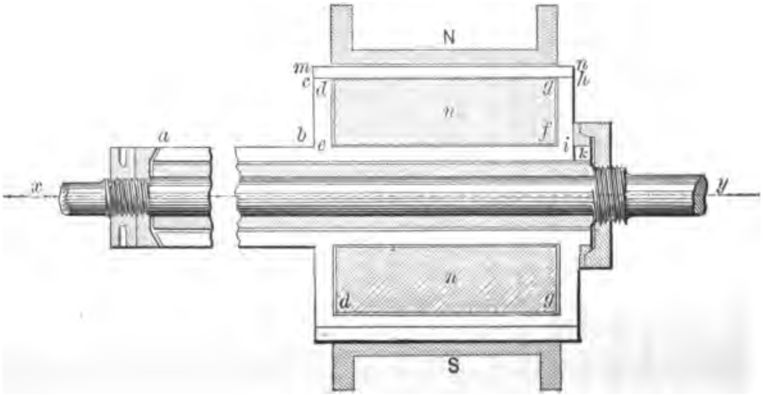


Cabella Armature.

strips. These are separately cut out, and consist each of a straight piece having two arms, and projecting at right angles. A sleeve of insulating material is placed over the axle, and around this these copper pieces are arranged to the number of some 240 or so, having their arms projecting symmetrically around in two radial sets, one near one end and the other near the other. The channel formed thus between the two sets is lined with insulating material, and then entirely filled up with soft iron wire wound around. Then straight strips of copper, eight millimeters broad and two millimeters thick, are screwed across the outside (like the bars of the Edison armature) from the ends of one set of radial projections to the end of the others, forming the parallelogram section. But, in order to connect the ring all around in a continuous circuit, these external strips of copper are connected at their two ends to pieces which project not from the same internal copper strip but from adjacent strips. Thus an external bar will connect the anterior end of the first strip with the posterior end of the second; and so on. Every third strip is carried along the axle and connected to a segment of the collector. This construction is certainly simpler than that of the Edison armature, and might be adapted to many different types of machines. According to Professor Ferrini, one of Cabella's armatures placed between the poles of a 60-light Edison ("Z," old pattern) instead of its ordinary armature, increased its power so that it could be used over 100 lamps.

Passing from ring-armatures, I come

Fig.25

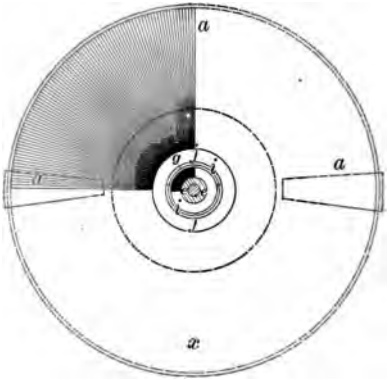


Cabella Armature. Section.

to another type of machine having disc armatures. The earliest machine of this type was due to the indefatigable Mr. Edison, who built up his disc of radial bars connected at the outer ends by concentric hoops, and at the inner by plates or washers. Each radial bar communicates with the one opposite to it; and the disc thus built up is rotated between the cheeks or pole-pieces of very powerful field magnets, which very nearly meet, and which therefore yield an enormously powerful field. I cannot hear of any of these disc dynamos having yet come into practical use.

Another type of disc dynamo has been invented by Sir. W. Thomson. In this case, the armature is a flat wheel, very like a flattened bicycle wheel. It is shown at *a* in Figs. 26, 27 and 28. The radial arms or spokes of the wheel, in which the currents are induced, are all connected at their external ends to the copper rim, but at their internal ends are carefully insulated and connected each to a segment of a collector or com-

Fig. 26



ARMATURE OF SIR W. THOMSON'S WHEEL DYNAMO.

mutator *g*. As in Edison's disc machine, so also in this, the thin disc rotates between the poles of very powerful field magnets, which, in the case of Sir W. Thomson's machine, are semi-circular in form. Sir W. Thomson also pivots his armature with its axis vertical, and spins it like one of his gyrostats. Unfortunately, the machine has not shown itself to be in practice a success. Its construction necessitates a very high speed, else

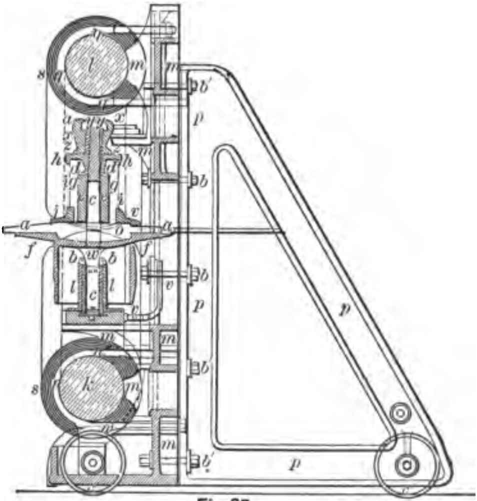
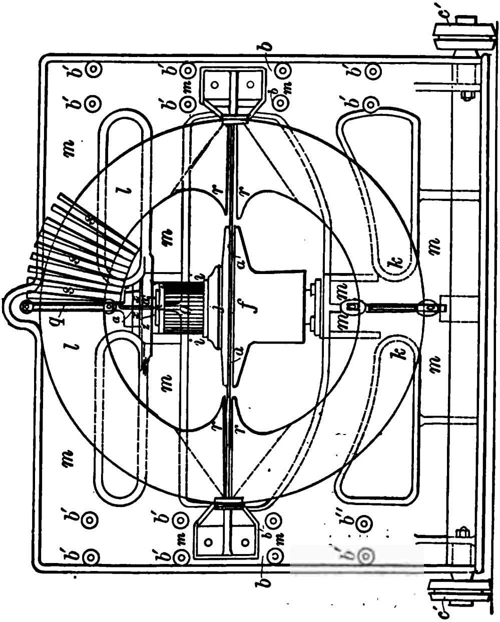


Fig.27

Sir W. Thomson's Wheel Dynamo.
Vertical Section.

the electromotive force would be small. If the radial bars, instead of being all joined to one rim, were united by overlapping insulated rings, each one to the one next to that diametrically opposite, and a connection brought round again at the hub to the next but one from that at

Fig. 28

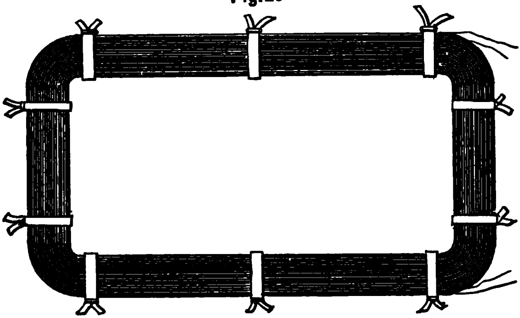


SIR W. THOMSON'S WHEEL DYNAMO. FRONT ELEVATION.

which the outer rim started, then, applying similar connections all round, the radii would all be connected in circuit, and a much higher electromotive force might be obtained. I am not aware that any disc so connected has yet been tried.

Some improvements have also been made in the Elphinstone-Vincent machine. The sections of the armature of this machine are wound separately in parallelogram forms like that shown in Fig. 29, and the separate sections are then fixed upon the periphery of a papier-maché cylinder which is mounted so as to rotate between powerful field magnets and internal field magnets whose poles

Fig.29

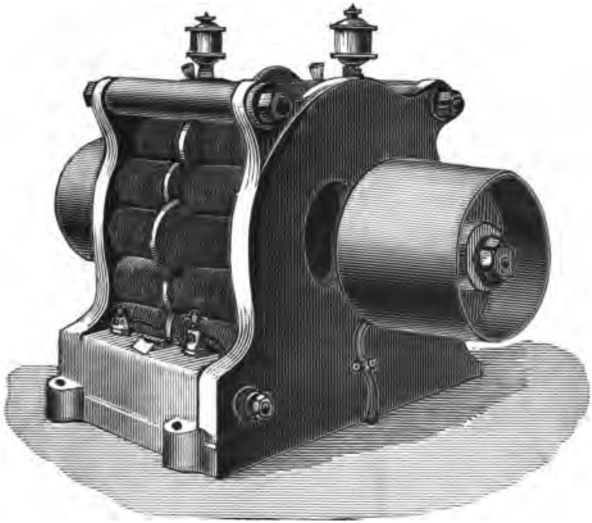


PARALLELOGRAM COIL FROM THE ELPHINSTONE-VINCENT ARMATURE.

reinforce the field. In the improved machines the parallelograms of wire are so arranged that the overlapping ends lie outside the ends of the polar surfaces of the field magnets, which, therefore, can be brought very close to the surface of the rotating cylinder. Amongst other improvements, also, segments of the collector are internally cross-connected, so that only two brushes are needed instead of six as formerly. Several improvements in mechanical details have also been made.

In alternate current machines something has also been done. The Ferranti-Thomson machine, which, at the date of my Cantor Lectures, had just made its appearance, has been considerably perfected. By the courtesy of Mr. Hammond, I am enabled to show Figs. 30 to 33, illustrative of the "1,000-light" dynamo, and of its working parts. Externally, the machine is scarcely charged at all; the driving pulley being a little larger in proportion. Internally, considerable changes have been made, and in

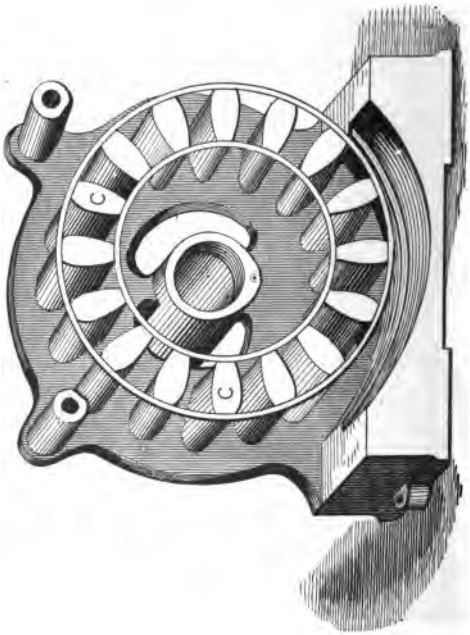
FIG. 30.



THE FERRANTI THOUSAND-LIGHT DYNAMO.

these the hand of the experienced mechanical engineer is apparent. The framework of the machine is now cast in two halves, which are afterwards bolted together. Fig. 31 shows one-half of the carcase of the machine with its projecting circle of magnet cores, C, which re-

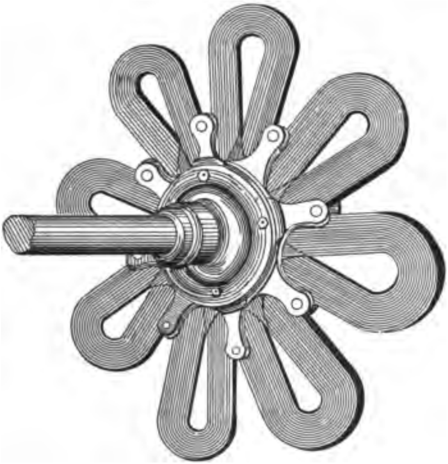
Fig. 31



HALF-CARCASE OF FERRANTI DYNAMO.

ceive the field magnet coils. The armature, originally a single zigzag piece of copper, has assumed the form shown in Fig. 32, in which it may be seen that the convolutions are multiplied, and are held

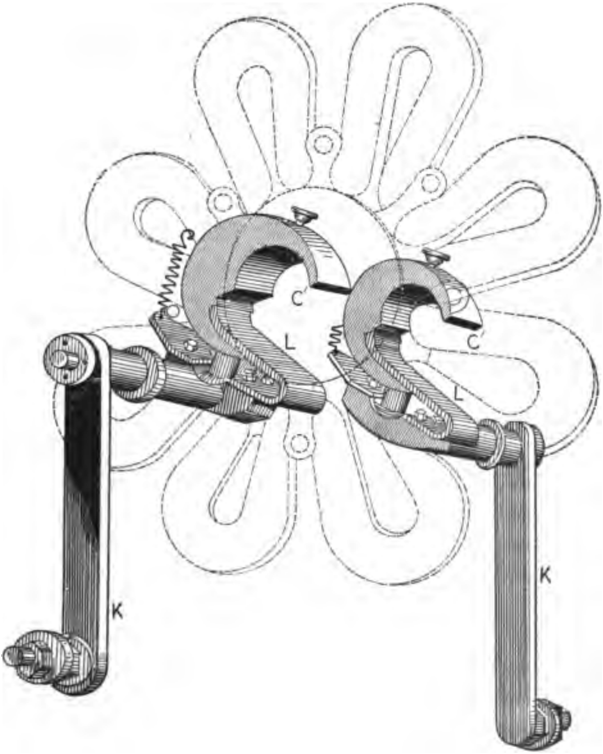
Fig. 32



Ferranti Armature.

in their places by bolts through a star-shaped piece of brass which also serves to carry to one of the two collectors the connection with one of the zigzag copper strips. There are in fact three complete circuits of copper strips in the armature connected in parallel arc. They begin at three of the alternate four bolts of the star-shaped piece, and folding around one another they all eventually unite with a second and inner star-shaped piece, which communicates with the second collector. Each strip makes ten turns around the zigzags, so that there are thirty layers, all well insulated from one another by strips of vulcanized fiber. This armature is 30 in. in diameter, and a little more than ½ in. thick in the upper convolutions, so that the opposite poles of the field magnets can be brought very close together, and a very powerful field produced. The entire armature weighs only 96 pounds. The most extraordinary part of the machine is, however, the arrangement adopted for conveying the currents to the external circuit. The axle carries on either side of the armature an insulated collector ring of bronze, to which the afore mentioned star-shaped pieces are respectively connected. Instead of brushes, solid pieces of metal, shown at C′ C′, Fig. 33, are employed to collect the current. These collectors hook on over the collecting rings, and bear against about 180°

Fig.33



COLLECTORS OF FERRANTI DYNAMO.

of the periphery of each ring. They are fixed on universal joints, and held by springs from rotating. Copper strips connect them to the terminals of the machine. The arrangements for lubricating the bearings are extremely perfect. The machine requires a speed of 1,400, and weighs 1½ tons. Mr. Ferranti has also designed a slow-speed dynamo to run at 800 revolutions per minute, and feed 500 lamps.

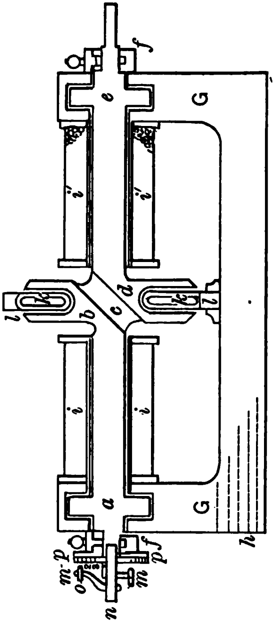
A very large alternate current machine was shown at the late Electrical Exhibition at Vienna, by Messrs. Ganz, of Buda-Pesth. It was capable of furnishing light for 1,200 Swan lamps (20 candle power each). This dynamo, which in some points resembled Gordon's well-known machine, was constructed according to the Mechwart-Zippernowsky system. The thirty-six bobbins of the field magnet were set concentrically on an iron frame, and rotated within an outer circle of thirty-six armature bobbins. The field magnet coils were, in fact, the fly-wheel of the high-pressure compound engine which drives the machine and its exciter. The diameter of the rotating part was 2½ meters. A salient feature of this machine is the fact that any one of the coils, either of armature or field magnets, can be removed from the side of the machine, in case such are needed. The whole fly-wheel can, in this way, be taken down by one man in a few minutes. An electrical efficiency of 85 per cent. is claimed for this machine.

Of one other class of machines—the unipolar dynamo—I had intended to say something. It is a remarkable thing that, though to my knowledge a great deal of attention has been paid lately to machines of this type, no one has yet succeeded in designing a practical unipolar dynamo. There seems to be some hiatus in the theory of this class of machines, for the very singular fact remains that those which are designed in defiance of precautions to avoid wasteful internal eddy currents will work, though badly, and those designed with such precautions will hardly work at all.

There are two or three other new designs for machines, which, at present, can hardly be called anything but curiosities. There is, for example, a design for a dynamo (a drawing of which is given in Fig. 34), by Sir Charles Bright, in which the field magnet coils and armature stand still, but in which the iron cores and the brushes rotate. There is another design by Professor G. Forbes, in which part of the field magnets rotate. Mr. C. Lever has designed a machine on somewhat similar principles to the foregoing. I have myself essayed an alternate current machine, in which both armature and field magnets stand still, while laminated pole pieces alone revolve. I hear also of a dynamo designed in the States in which there are no field magnets, only two revolving armatures.

And now I have left myself no time to deal with the third branch of my subject, namely, the dynamo in its functions as a mechanical motor. In this branch also much progress has been made. If time permitted I would speak of the motors

Fig. 34



Sir C. Bright's Suggested Dynamo.

designed by Professors Ayrton and Perry, which are successful to a very remarkable degree in yielding a great mechanical power in proportion to their weight. I might have been inclined to say something of the attempts made by the same able electricians to produce a self-governing motor by various devices of centrifugal and periodic governors, and also by using an ingenious differential winding. I might tell you how I have myself worked at the question from a different point of view, and have sought to govern motors so that they shall run at a uniform speed, by devices which will not wait until the speed changes before the act, but by devices depending upon the variations in the load of the machine, in short, upon dynamometric governors instead of centrifugal ones. These things must, however, wait until some more convenient season. Time will only admit of my showing you here, in conclusion, a model designed by Mr. C. Dorman to illustrate the graphic law of efficiency of motors, which I put forward in my Cantor Lectures, and which I am happy to learn has since been largely used in many different countries.

To sum up, then, it may be observed that in every department under review, the story of the past fifteen months is one of solid progress. It has been, it is true, progress of a quiet and perhaps of a commercial rather than a scientific order, yet, as I have shown you, one in which practice and theory have gone hand in hand. It is true that in some few points theory is ahead of practice, but in a still larger number practice is ahead of theory. It would be a great boon to us if our theoreticians could bring up theory to the level of practice in some of the simplest facts. We do not even know the exact law of the saturation of iron in electro-magnets, and content ourselves with formulæ, which we *know* to be incorrect. Of the laws of induction of magnetism in circuits partly consisting of iron, partly of strata of air, or of copper wire, we know very little. We want some new philosopher to do for the magnetic circuit what Dr. Ohm did for the voltaic circuit fifty years ago. There is ample room for progress yet in theory as well as in practice; and the perfection of theory means the deliverance of practice from arbitrary rules of thumb, and from the blunders of inexperience which have so retarded progress in the past. The history of the past fifteen months, however, gives great encouragement for the future, because it shows how much may be done, even in the face of great commercial depression, by those whose knowledge and experience give them a deliberate faith in the future, and whose efforts are directed toward no uncertain end. A steady development toward the yet far distant goal of perfection is going on unceasingly. The progress of which I am permitted to be the chronicler to-night is progress of the good and substantial kind, that owes nothing to the excited rush of Stock Exchange speculations, and which, not having been nurtured at an unhealthy fever heat, is destined to be of permanent value.

DISCUSSION.

The Chairman said they were much indebted to Professor Thompson for the extremely clear and able manner in which he had brought forward the progress of dynamo-electric history, and he was very much pleased to find that in that progress he had given the first place to practice, and the second place to theory. He had always found theoretical men rather inclined to look with a certain amount of disdain upon practical men, and to think that practical men knew nothing about their subject unless they followed the dictates of theorists. But a change seemed to be coming over the spirit of the dreams of philosophers, and they were now paying much more attention to the teachings of experience than they used to. Professor Thompson had shown how, during the past 15 months' progress, the lead had been taken by practical men; and he had been rather amused at this, because not much more than a week ago he heard him make similar remarks upon a paper brought before the Royal Society by

Professor Hughes, one of the most wonderful experimenters and discoverers of the present day. Professor Hughes succeeded, with pins, bodkins, bonnet wire, match boxes, tin kettles, and similar pieces of apparatus, in extracting from nature some wonderful secrets, and he had brought out some very beautiful instruments, which had been the result of incessant toil and constant experiment in every shape and form. Professor Thompson, at the Royal Society, gave the theory after Professor Hughes had shown his instruments, and at the end of the paper expressed surprise that Professor Hughes' instrument accorded with his theory. This was much what he had told them now, though not quite in the same words, that after all, experience was the only safe guide in teaching one how to make instruments for real practical work; and theory was a very good servant indeed when it came afterwards, and gave a plain, simple, unvarnished tale, which all could understand, to enable them to understand the peculiar action which had taken place.

Professor Thompson had alluded to the theory of the dynamo machine, and divided his theories into three—the physical, the algebraical, and the geometrical; and he was bound to say that his own diagramatical representation of the action of dynamo machines, and of the performance of magnetic fields, were perhaps the most interesting part of his paper. The way in which he had worked out the magnetic field had taught everybody more about this subject than they knew before. But he must say that he objected *in toto* to this application of the term theory to explanations which Professor Thompson had given of the action of the dynamo machines. Theory was neither algebraical nor geometrical. What Professor Thompson called theory was an explanation—a mode of representing what took place. But a theory was more than that; it was an explanation—a mental picture —of what took place in nature which placed it beyond mere hypothesis. For instance, the theory of light was an explanation of a certain physical action which took place in the universe, which enabled the vibrations of the sun to be represented in our eyes. The theory of heat was something which enabled us to conceive of matter itself vibrating and the space around it also vibrating in unison; but he objected to applying the term theory to either an algebraical or geometrical description of the actions of the dynamo or any other machine. He, and all other electricians, wanted to have some idea conveyed to their minds of what took place in a wire, in iron, and in the space occupied by the iron and the wire, which produced those marvelous results which they saw in the electric light and in the transmission of force, and to this sense he would confine the word theory.

Mr. Liggins said he was not qualified to speak on the scientific aspect of the question, but he was much interested in hearing of the progress which had been made during the last sixteen months. He was glad to find that some of the bubble companies were going to the wall, and when some of the systems which had very little merit were out of the way, there would be a chance for some simple and practical method to come into use. One day last week, at the Edgwareroad Station, he noticed that the electric arc light was wonderfully steady, and the superintendent informed him that an improvement had just been introduced, which reduced the cost from £200 to £8. That was all he heard about it, for he had not time to inquire further particulars, but he hoped the time was not far distant when the public would derive a benefit from some of these improvements.

Mr. Percy Sellon then gave some particulars of the Victoria machine. He said that taking an original Schuckert machine, capable of giving 60 incandescence lamps of a certain power, by substituting four poles for two, the mass of which, both in iron and copper, was very little in excess of that in the original two, and using identically the same ring, they obtained 100 lights and a much better result in the commutator. From the old

Schuckert machine they got a very similar diagram to that which had been shown, among these integrated from Isenbeck's as a bad one with false inductions (Fig. 6), the output of the machine being crowded into two bobbins, and on the other side there was a back electromotive force which caused considerable sparking. This was almost entirely removed by the use of four poles, and at the same time the internal resistance was brought down to about one-fourth what it was before. In constructing large dynamos for 500 lights and upwards, they were increasing the number of poles to 6 and 8, and eventually, probably, they would go to twelve for very large machines. The great advantage of this was that when you brought the poles together you had a given number of lines of force crowded into a very much smaller space; the distances of the centers between north and south polarity were much less, and whilst the number of poles increased, the intensity of the field remained the same, and, therefore, a given length of wire and iron, revolving at a certain speed, would give a decidedly higher result. With regard to the system of compound winding, he should say that a great deal of the credit was due to an *employe* of the firm, Mr. C. Watson; and it was applied without any formula or mathematics, and the very first machine constructed without any experiments gave as good a curve as the one shown on the diagram. It gave a difference of potential of only about 3 per cent. when the whole number of lamps was at work, and when the armature was simply working on the shunt. That showed theory was not always necessary.

Professor Thompson, in reply, said he did not agree with the Chairman's criticism on his use of the word theory. He thought that he had indicated that these three methods were really three aspects of the theory. The number of lines of force which he had been dealing with might be expressed by certain length of line, geometrically, or by the symbol n alphabetically, or when viewed optically, by a mere pictorial demonstration. What some people wrote *n* for, other people indicated by drawing a line in a certain direction. It was only another way of arguing about the things themselves. He wanted them not to ignore those essential considerations which constituted the true theory, and which underlay the mere facts of observation. They were approximating to that theory by one process or another, sometimes by algebra, sometimes by geometry, sometimes by diagrams, and it made all the difference between working intelligently and unintelligently to have a principle to guide one. He had been trying to discover, both from *a priori* considerations, and from the teachings of experience, what the principles were which ought to guide practice; and he thought he might claim to have vindicated the claims of theory. It was quite true that theoretical men had been sometimes loth to allow any consideration to practical men; but, on the other hand, practical men would often refuse to have anything to do with theory. The vindication he wanted to put forward was this: in his Cantor Lectures, and since, he had been working diligently at the curves of potential around the commutator, and to-night he had connected them with the curves of Isenbeck. Part of the improvement he had noticed in the Schuckert machine was directly due to the advice he had given Mr. Mordey, and to the world at large, on shaping of the pole-pieces to that form which would give the best result on the commutator in respect to the rise of the curve of potentials. Originally the Schuckert machine had great shoes of iron as pole-pieces around it, now they were narrowed and tapered. It was found that where you had pole-pieces on the two sides of an ordinary cylindrical Gramme ring, it was better to have them curved around through a large arc, because it gave a flatter field, and the cutting of the lines of force was more regular. Now they were finding that practice was leading in an exactly opposite direction for flat-ring machines with the poles at the sides; the shoes were being cut down into little narrow pole-pieces. Theory had led practice to that, and theory, too, had pointed out the relation between the curve of the potential and the induction due to the pole-pieces. After theory had indicated the source of error and a possible means of remedy, they had gone on experimentally cutting down the pole-pieces until they got the proper curve on the commutator. He might further claim, as a vindication of theory, that M. Gramme, who had had fourteen years' experience in constructing Gramme machines, and to whom they owed an enormous debt of gratitude, had not yet arrived at the real point which had been reached in England. M. Gramme confessed that this 12-pole machine of his was not yet perfect, and he (Professor Thompson) had little doubt that the reason was that he had great flat pole-pieces nearly meeting each other. He would stake his opinion on the fact that if he had only made the poles narrower he would have had a better curve of potential, a machine that did not spark so much. That was the deduction he should draw at once from the potential curve. He claimed that it was entirely admissible to call a generalization from which deductions of that kind might be drawn, theory; it was theory in the truest sense of the term, because it pointed the way for practice to follow. He did not require to know what electricity was, or what magnetism was in a piece of iron, or what was the ultimate form of the transfer of force across the space between them, before he used the word theory. He regretted that cold water should have been thrown on his attempt to raise the construction and design of dynamo machines above mere rules of thumb, which were the essence of practice when unenlightened by theory. Practice without theory went on blundering in the dark, and though it was possible to blunder into success, it was much more easy to blunder into failure. With regard to the invention which had been mentioned, which would reduce the cost from £200 to £8, he need hardly say he should be much interested in further details; he believed it was the first instance on record in which an inventor dared to claim to have reduced the cost more than 50 per cent., that being the usual reduction claimed in the stock phrase of company promoters.

The Chairman, in proposing a vote of thanks to Professor Thompson, said he did not apply the word "theory" in the sense he objected to. He thought that certain geometrical and algebraical investigations were essential in carrying out any practical question, but he objected to the use of the word "theory" to explain what was really better expressed by the word "principle." Prof. Thompson himself used the word "principle," and had detailed the principles that governed the action of the dynamo machines, and it had been in following these principles that such vast improvements had been made. He should like to have heard some description from Professor Thompson of a class of dynamo machine which was now coming into use daily very largely for the production of copper by the deposit of the metal from its salts. This was being done both at Swansea and at Birmingham. Mr. William Elmore, a hard worker in this field, who had works at Blackfriars, was setting up very large works at Swansea for the extraction of copper from impure ores by this method, and when next Professor Thompson brought the subject before this Society, as he was sure the council would insist upon his doing next year, he hoped that he would pay a little attention to those dynamo machines that were met with in other fields besides the production of electric light and the transmission of power. Again, he was rather disappointed to hear him pass by very lightly the performance of the Hockhausen machine, which was certainly the most distinguished feature of the Fisheries Exhibition. He did not think that that machine had received the attention it deserved, or been studied so carefully by Professor Thompson as others. Its performance was simply wonderful, and though he had not yet seen the Victoria machine, his own impression was that, of all those he had seen, the Hockhausen was decidedly the best. Perhaps Mr. Crompton's was an exception, for he had this advantage over Prof. Thompson that he had seen the performance of the Crompton machine. It was certainly a wonderful little thing. You saw before you apparently a lump of iron which was motionless and silent; it appeared motionless because it went so quickly, and it was silent because it was so beautfully made, but with that machine currents of electricity were produced that had increased the output of the form known as the Crompton-Burgin machine exactly 100 per cent. The great lesson to be learnt was this: advance was being constantly made in all these machines, an advance whose future they could scarcely see an end to, and every day they could perceive how, by the combination of theory and practice, they were developing the power of producing electricity to an extent which no one had dreamed of. What with the improvements such as had been mentioned that evening, with improvements in electric lamps and various other appliances, he did not think there was any chance of that end being reached which gas shareholders were so anxious to see.